Rock debris on glaciers: a mechanism for reducing glacier sensitivity to climate change

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Synopsis

Rock debris covering a glacier surface affects the local melt rate by regulating the amount of solar energy available for melting. Supraglacial debris with a thickness of about 2 cm or more insulates the ice, thereby reducing the heat flux. This reduction of melt rate allows heavily debris-covered glaciers to extend further down-valley than meteorological variables alone would suggest. Here we present a regional study of supraglacial debris cover in the Delta Mountains, a sub-range of the Alaska Range. Using remote sensing and in situ measurements we consider the following questions:

-How does glacier and debris-covered area change from 1986 to 2010?
-Can we estimate debris thickness remotely?
-How does debris affect melt?
-Will ice melt cease below two meters of debris?
-Is there a correlation between geologic setting and debris cover?

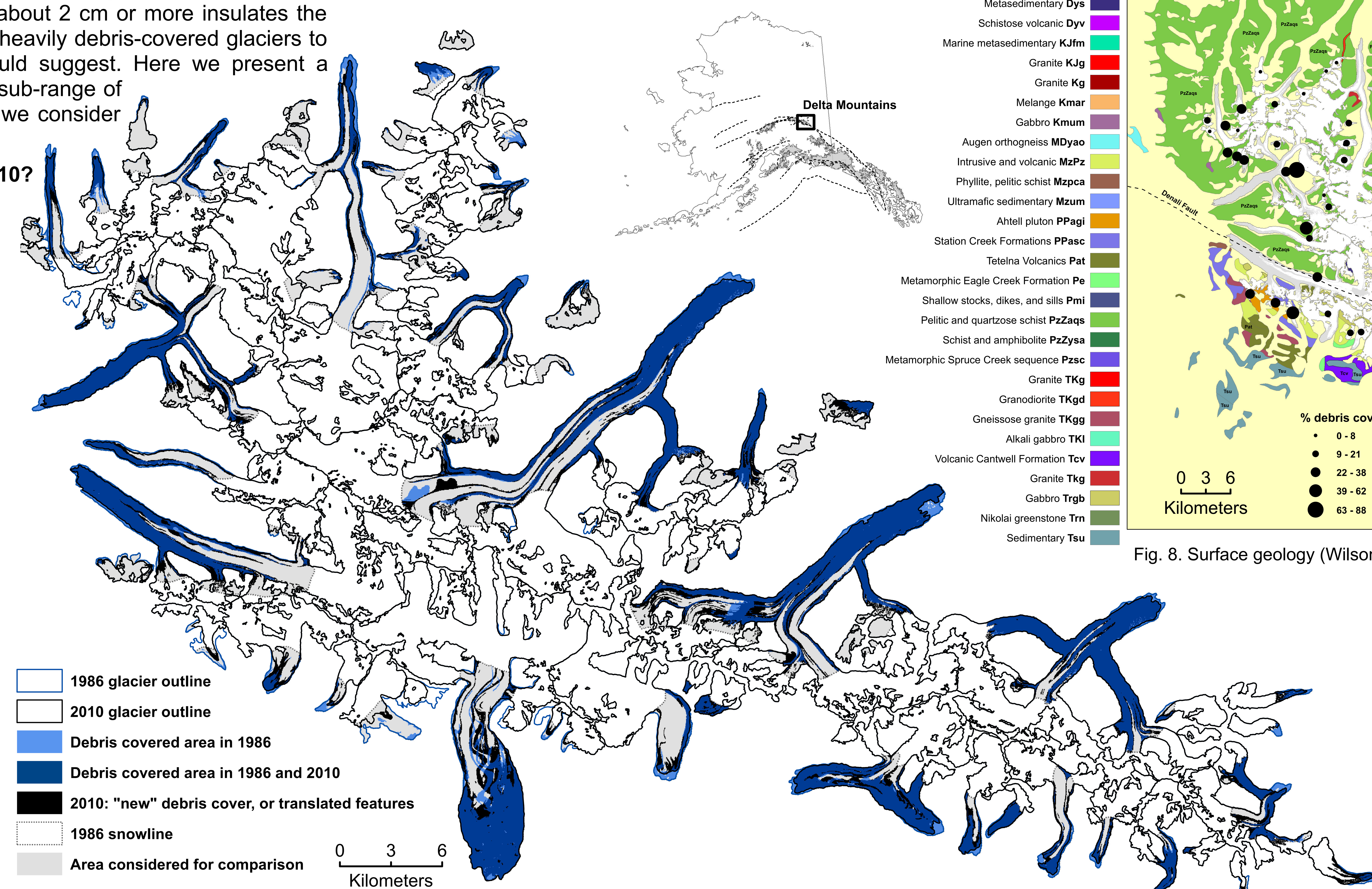

Fig. 1. Glacier area and supraglacial debris within the Delta Mountains, a sub range of the Alaska Range. Glacier and debris geometries were mapped for 1986 (blue) and 2010 (black). Due to year-to-year variations in snow line, comparison of debris cover was restricted to the glacier area below the lowest observed snow line (gray area). Glacier outlines were manually digitized from satellite imagery and subdivided at ice flow divides. Supraglacial debris was mapped using spectral image classification of Landsat5 imagery. Glaciers smaller than 1 km^2 were excluded from this study.

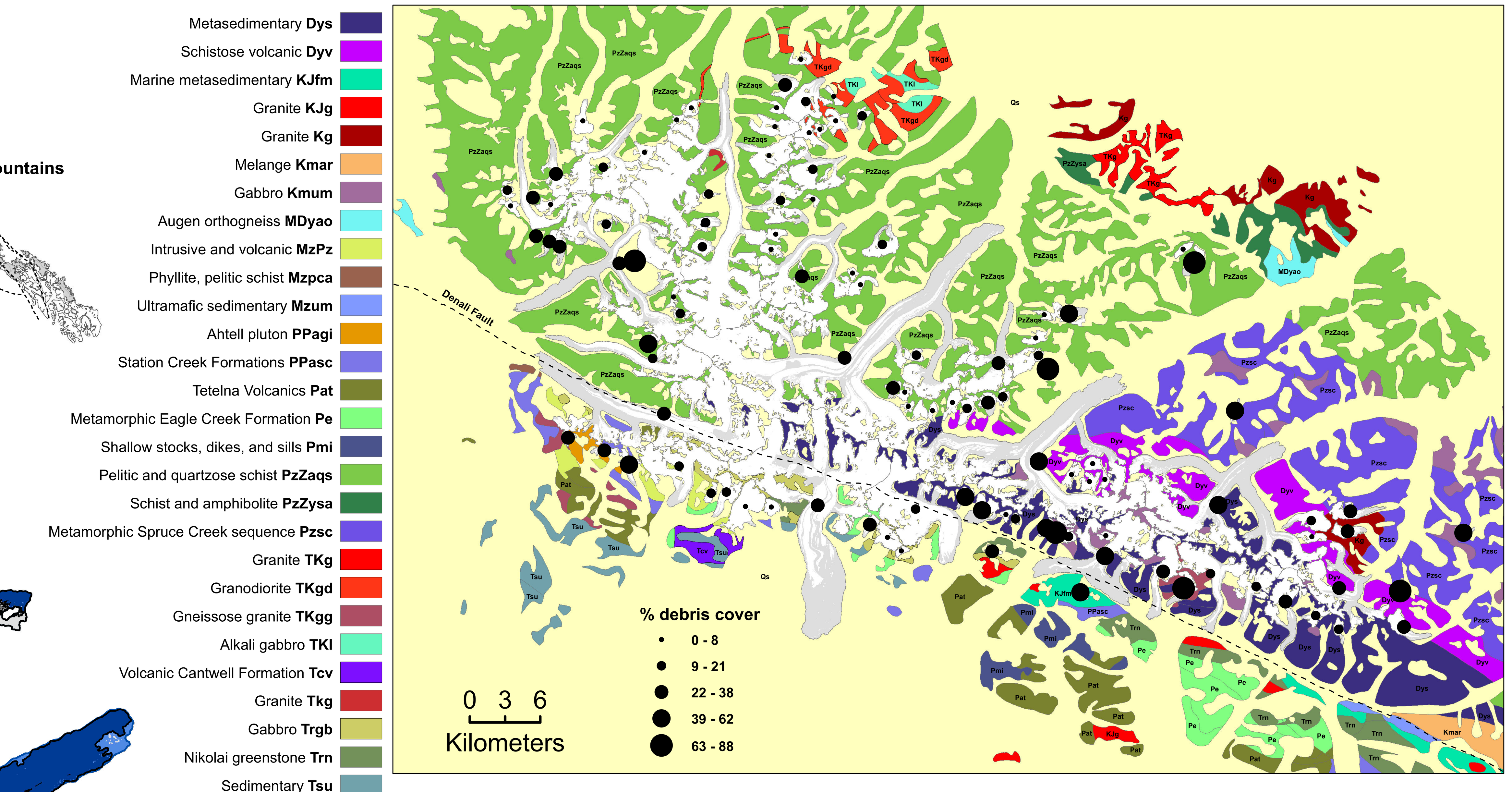

Fig. 8. Surface geology (Wilson et al., 1998) and percent debris cover per glacier (2010 geometry).

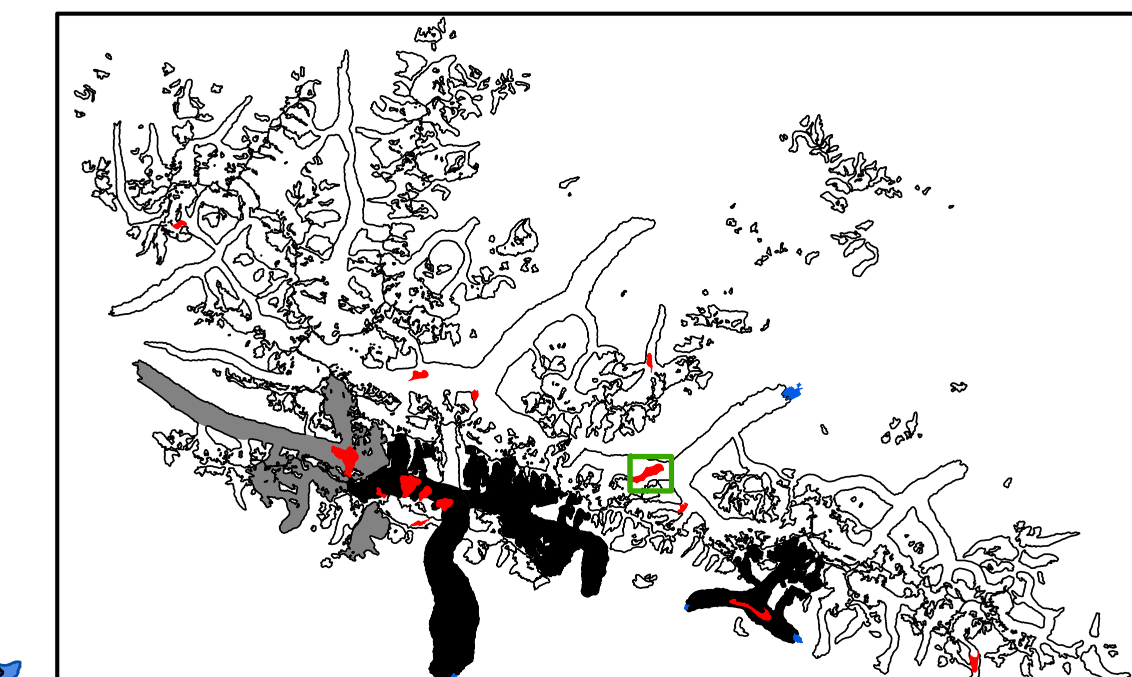

Fig. 9. Special considerations. Glaciers shown in black are surge-type. Gray glaciers are suspected surge-type or exhibit pulsing behavior. Red polygons are catastrophic supraglacial landslides, and blue polygons are terminal lakes (2010 geometry).

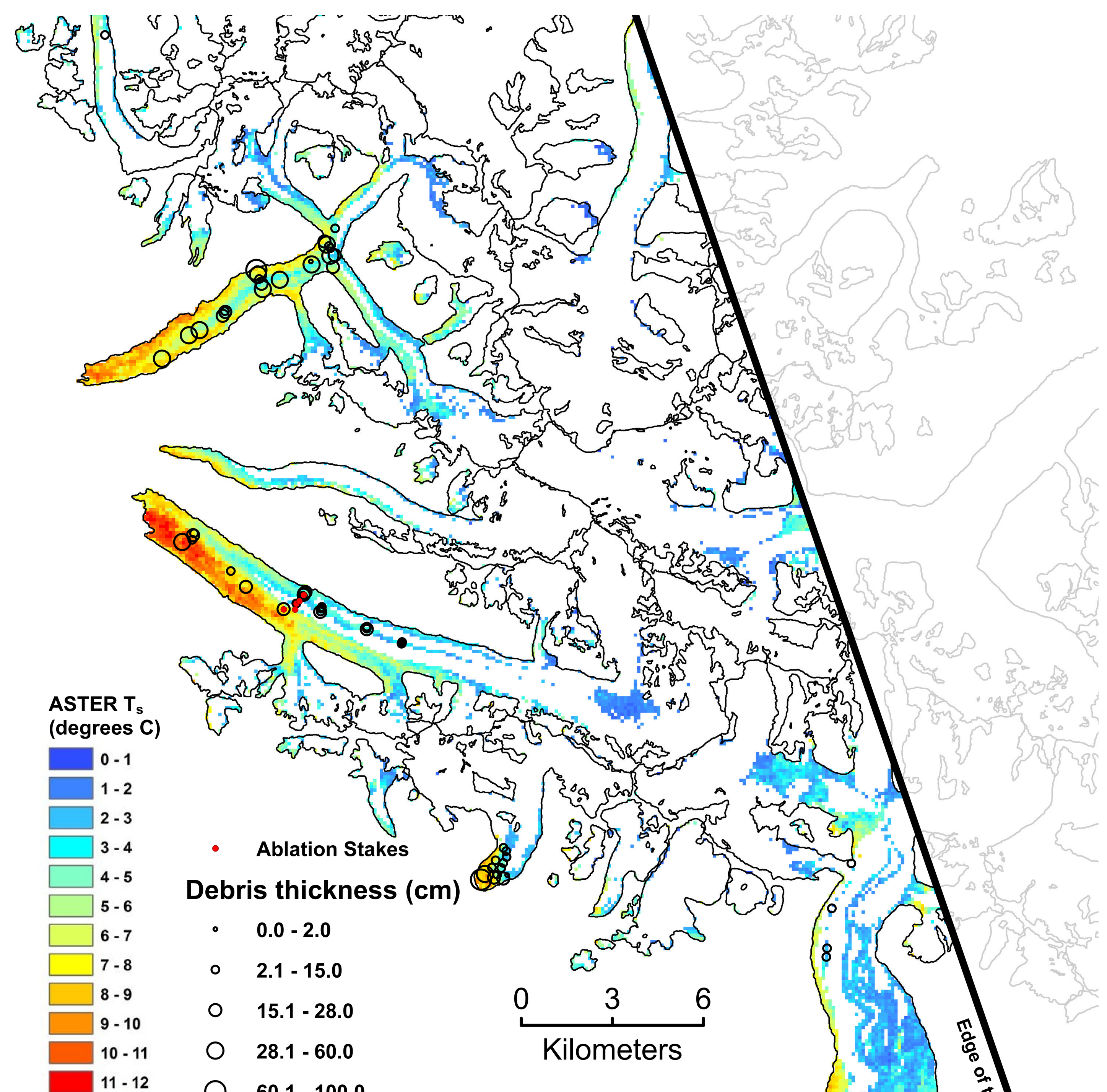

Fig. 2. ASTER-derived surface temperature (T_s) collected 2005-07-13 22:15 (local) clipped to debris-covered glacier area. Field measurements of debris thickness collected in 2011 are shown. Important to note is that glacier velocities in this region are on the order of 50m/yr and ASTER pixel size is 90 km^2.

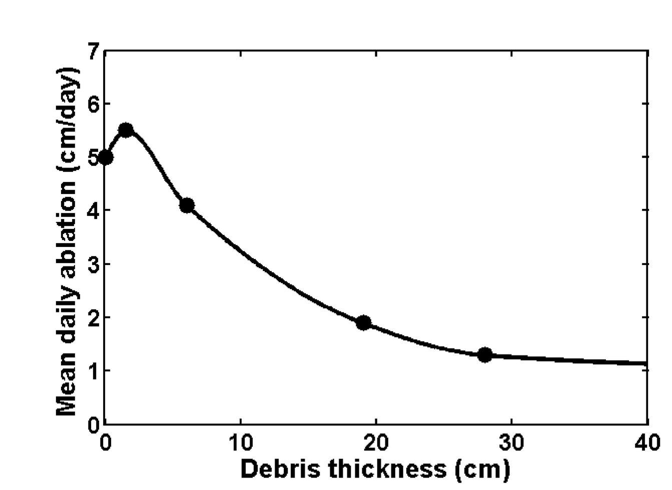

Fig. 3. The relationship between debris thickness and glacier melt rate. Measurements were collected at the red dots in Fig. 2 in 2011. The line is interpretation.

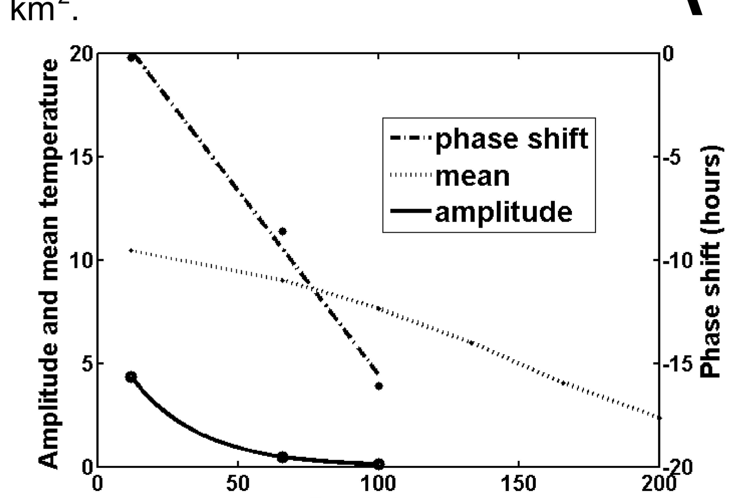

Fig. 4. Analysis of data from Fig. 5 on a diurnal scale assuming sinusoidal behavior. Notably, temperature at 2m depth are above freezing.

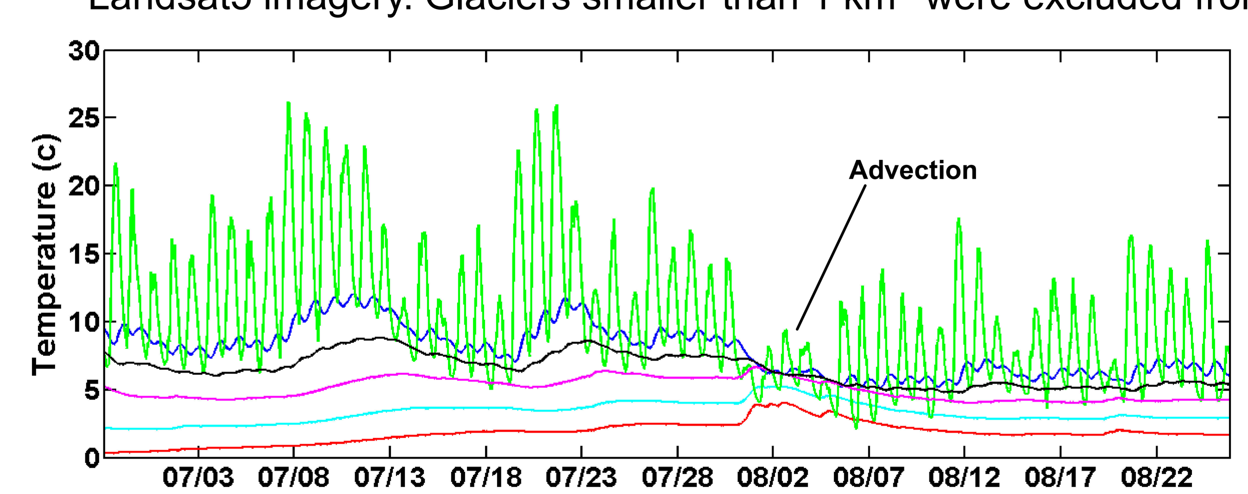

Fig. 5. Temperature profile through 2m of supraglacial landslide debris (location: green box Fig.9) collected in 2011. Each color corresponds to a thermistor and different depths: green, 12 cm; blue, 66 cm; black, 100 cm; purple, 133 cm, turquoise, 166 cm; red, 200 cm. A Fourier analysis of this data found a thermal diffusivity value of 1.86 $mm^2\ s^{-1}$.

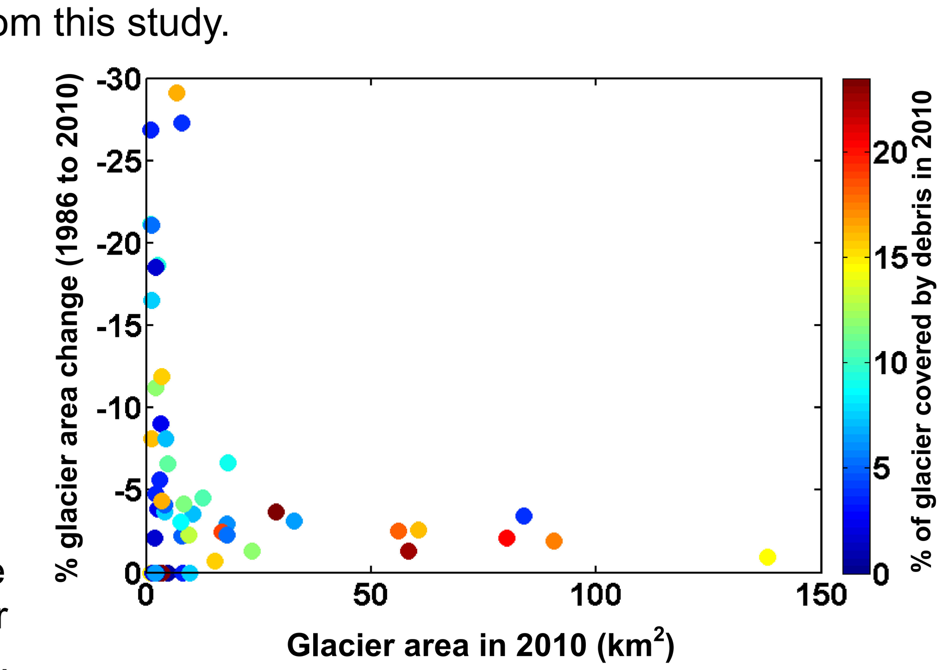

Fig. 6. Glacier area change vs. 2010 area for every glacier in the Delta Mountains (>1 km^2). Color represents the percentage of debris cover in 2010.

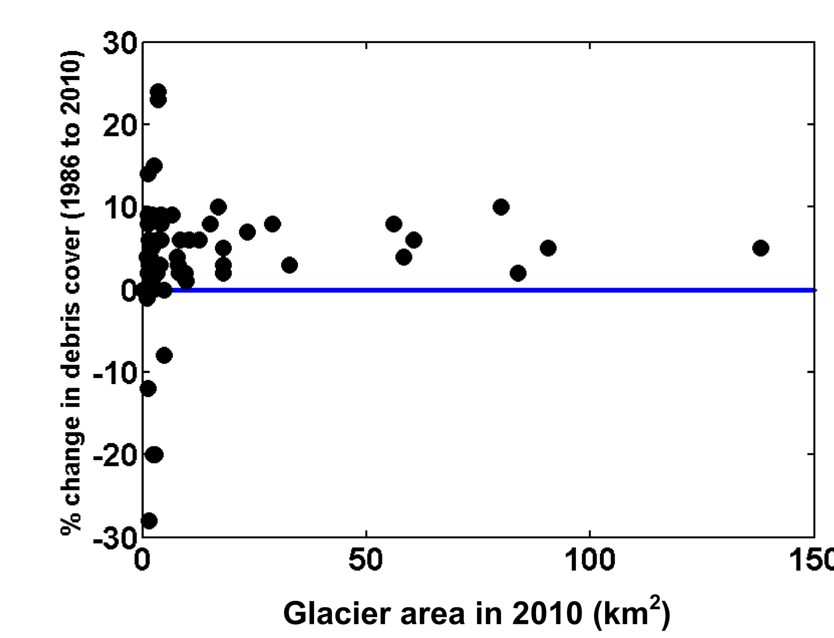

Fig. 7. Change in debris cover from 1986 to 2010 holding the glacier area constant at the minimum (in this situaton 2010 geometry). Values below the 0% line indicate error in the methodology.

19% of glacier area in the Delta Mountains was debris-covered in 1986; 23% was covered in 2010

From 1986 to 2010, glacier area changed from 984 to 942 km^2 (-42 km^2 or -4%)

From 1986 to 2010, debris-covered area increased from 188 to 216 km^2 (+28 km^2 or +13%)

Preliminary results suggest satellite-derived surface temperature reflects debris structure; extrapolation of melt vs. thickness will provide a regional melt reduction estimate

Above-freezing temperatures were measured under 2m of debris, showing there is energy available for melt

No obvious pattern was found between surface geology and percent debris cover